

# PATENT SPECIFICATION

1,024,393



NO DRAWINGS

1,024,393

Date of Application and filing Complete Specification: March 25, 1964.

No. 12707/64.

Application made in Japan (No. 14251) on March 30, 1963.

Complete Specification Published: March 30, 1966.

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Index at acceptance:—C3 R(22C12, 22D3A, 22N1A, 22N1B, 22PX, 22T1)

Int. Cl.:—C 08 g

## COMPLETE SPECIFICATION

### Process for Polymerizing N-Carboxy- $\alpha$ -Amino Acid Anhydrides

PATENTS ACT, 1949

SPECIFICATION NO. 1,024,393

In accordance with the Decision of the Superintending Examiner, acting for the Comptroller-General, dated the 27th day of January, 1967, this Specification has been amended under Section 29 in the following manner:—

Page 3, line 49, delete "2 - methyl propionaldehyde"

Page 3, line 51, delete "acetoacetic aldehyde"

THE PATENT OFFICE,  
23rd March, 1967

D 83812/6

PATENTS ACT, 1949

SPECIFICATION NO. 1,024,393

The following corrections were allowed under Section 76 on the 9th day of February, 1967.

Page 2, in the table, for "Optically" read "Optically"

Page 3, line 60, after "acid" insert comma for "ether" read "ethyl"

THE PATENT OFFICE,  
23rd March, 1967

D 83812/11

anhydrides are equal in their reactivity regardless of their optical activity.

40 In addition, it has also been found that no isomerization or racemization occurs in the course of that method of polymerization.

Therefore, according to the method of polymerization mentioned above, poly-L-amino acid is obtained from N-carboxy-L-amino acid

ponding compounds by the formerly known method:

For practicing this invention, all N-carboxy- $\alpha$ -amino acid anhydrides containing at least one asymmetric carbon atom are suitable. That is to say, N-carboxy-amino acid anhydrides made from neutral amino acids such as alanine, leucine, nor-valine, isoleucine and  $\alpha$ -

[Price 4s. 6d.]

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## COMPLETE SPECIFICATION

### Process for Polymerizing N-Carboxy- $\alpha$ -Amino Acid Anhydrides

We, ASAHI KASEI KOGYO KABUSHIKI KAISHA, a Corporation organised under the Laws of Japan, of 25-1 Dojimahamadori-1-chome, Kita-ku, Osaka, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to a process for the polymerization of N-carboxy- $\alpha$ -amino acid anhydrides.

15 It is well known that N-carboxy-amino acid anhydrides, especially N-carboxy- $\alpha$ -amino acid anhydrides in the presence of suitable initiators such as water, alcohols or amines, undergo polymerization with the loss of carbon dioxide to form polypeptides of high molecular weight.

20 We have already found that N-carboxy-amino acid anhydrides are polymerized using as initiator organometallic compounds such as some new classes of compounds containing both metal atoms and organic radicals, metal alkoxides and metal chelates to give high molecular weight polyamino acids (British Patent Application No: 25231/63, Serial No. 996,760). It has also been found that certain organometallic compounds in the presence of water or alcohol or in the presence of their reaction products with water or alcohol, show greater ability of initiating polymerization.

25 That method of polymerization can be applied not only to the optically active amino acids but also to racemic or optically inactive amino acids, since N-carboxy-amino acid anhydrides are equal in their reactivity regardless of their optical activity.

30 In addition, it has also been found that no isomerization or racemization occurs in the course of that method of polymerization.

35 Therefore, according to the method of polymerization mentioned above, poly-L-amino acid is obtained from N-carboxy-L-amino acid anhydride, and poly-DL-amino acid (racemic, optically inactive) can be obtained from N-carboxy-DL-(racemic) amino acid anhydride.

40 We have developed this method further, and have found a method of stereospecific polymerization which, for example, enables optically active polyamino acids to be obtained from N-carboxy optically inactive racemic amino acid anhydrides.

45 The method according to this invention comprises polymerizing N-carboxy- $\alpha$ -amino acid anhydrides containing at least one asymmetric carbon atom in the presence of an organic compound having an asymmetric carbon atom and active hydrogen atom (which includes enolizable hydrogen) and an organometallic compound containing a metal of Group I, II or III of the Periodic Table, or simply in the presence of such an organometallic compound which contains an asymmetric carbon atom.

50 This method is a stereospecific polymerization with respect to the asymmetric carbon atom or atoms of the starting N-carboxy- $\alpha$ -amino acid anhydride, and can be used to produce either polymers which are optically active, whether or not the starting N-carboxy- $\alpha$ -amino acid anhydride is itself optically active or is a racemic mixture of isomers, or polymers which are optically inactive but which have properties different from and superior to those of the corresponding random optically inactive polymers. The method can be used in the manufacture of products such as fibres or films having improved properties which cannot be obtained from the corresponding compounds by the formerly known method.

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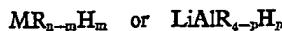
85 For practicing this invention, all N-carboxy- $\alpha$ -amino acid anhydrides containing at least one asymmetric carbon atom are suitable. That is to say, N-carboxy-amino acid anhydrides made from neutral amino acids such as alanine, leucine, nor-valine, isoleucine and  $\alpha$ -

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phenylalanine;  $\omega$ -esters of N-carboxy-acidic amino acid anhydrides such as aspartic acid and glutamic acid; and N-carboxy-amino acid anhydrides whose amino groups, carboxyl groups, hydroxyl groups or thiol group are masked, such as O-benzyl serine, O-acetyl serine, O-acetyl threonine,  $\epsilon$ -acetyl lysine,  $\epsilon$ -carbobenzoxy lysine,  $\delta$ -acetyl ornithine and methionine, can all be utilized. Besides, a mixture of any two or more of these compounds can be used.

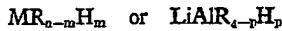
The catalysts of this invention are as follows:

(I) an organometallic compound having an asymmetric carbon atom, and represented by the following general formula:

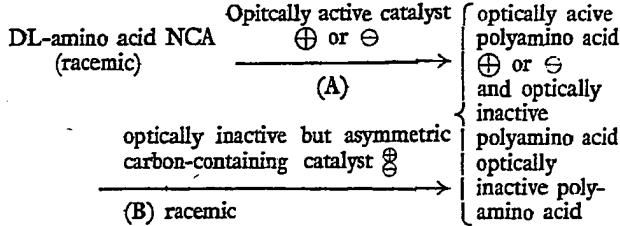


(wherein M represents a metal of Groups I, II or III of the Periodic Table; R, which may be the same or different, represents an organic group having an asymmetric carbon atom, i.e. an alkyl, alkenyl, cycloalkyl, cycloalkenyl, aralkyl, alkoxy, cycloalkoxy, arylalkoxy, aryloxy, dialkyl amino, alkylarylamino, alkylthio, cycloalkyl thio or acyloxy group having an asymmetric carbon; n represents the valency of the metal, being 1, 2 or 3; m represents 0, 1 or 2; and p represents 0, 1, 2 or 3 or

(II) an organometallic compound having the general formula:



(wherein M represents a metal of Groups I, II or III of the Periodic Table; R, which



The differences in properties between the optically inactive polyamino acid so obtained and optically inactive polyamino acid obtained by the conventional method will be described below.

The obtaining of optically inactive polyamino acid by means of the method (A) means that the total optical rotary power of a nearly 100% polymerized polymer is zero or nearly zero, while other properties are nearly or quite identical with those of optically active polyamino acid obtained according to the same method.

Method (B) is the more convenient and favourable one, in which both the reaction due to  $\oplus$  catalyst and the reaction due to  $\ominus$

may be the same or different, represents an organic group, i.e. an alkyl, alkenyl, cycloalkyl, cycloalkenyl, aralkyl, alkoxy, cycloalkoxy, arylalkoxy, aryloxy, dialkylamino, alkyl aryl amino, alkylthio, cycloalkylthio or acyloxy group; n represents the valency of the metal, being 1, 2 or 3; m represents 0, 1 or 2; and p represents 0, 1, 2 or 3), and an organic compound having both an active hydrogen atom and an asymmetric carbon atom which have at least some interaction with above-mentioned organometallic compounds which are also present in the polymerization system.

Thus, in the case (I) an organometallic compound, which contains an asymmetric carbon atom and which may or may not be optically active is used as the catalyst whereas in the case (II) an ordinary organometallic compound, which need neither be optically active nor contain an asymmetric carbon atom and an organic compound having both an active hydrogen atom and an asymmetric carbon atom and which may or may not be optically active, are both present in the polymerization system.

If desired to obtain optically active polyamino acid it is necessary to employ an optically active substance in both cases (I) and (II), but if it is simply desired to obtain a polyamino acid with improved properties, an optically inactive compound (e.g. an equimolecular compound or mixture of D- and L-isomers) can be utilized so long as it contains an asymmetric carbon atom.

This method is schematically illustrated as follows:

catalyst take place simultaneously and equimolecularly.

Optically active organometallic compounds can be obtained by reaction between metals or organometallic compounds and optically active substances.

In the case of optically active substances, either enantiomeric isomer can be utilized.

The organic compounds containing an asymmetric carbon atom are, as described before, the compounds which have at least some interaction with the selected organometallic compound (for example to react therewith or to form complexes) and are preferably bulky ones having an asymmetric carbon atom as near to the functional group which reacts

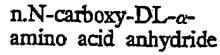
be zero or very close to zero when the polymerization is effected completely and the whole quantity of N-carboxy-DL-amino acid anhydride is converted into polyamino acid.

5 When the polymerization is carried out using racemic compounds, the polyamino acid obtained exhibits no optical rotatory power, but it is apparent that the polymerization is essentially the same as one carried out using

10 the corresponding optically active compounds because the polymer obtained is identical, except in optical properties, with that obtained by complete polymerization by means of an optically active catalyst and is different from a

15 polymer obtained by conventional means using a catalyst which does not contain an asymmetric carbon atom, for example tri-n-butylamine.

20 The amount of organometallic compound used is usually within a range from 0.001 to 10 (mole) preferably from 0.01 to 5 (mole) %, based on the N-carboxy amino acid anhydride to be polymerized. In a case in which an optically active or racemic organic com-



In the above formula:

50  $\pm$  catalyst = racemic catalyst  
 $+$  or  $-$  catalyst = levorotatory or dextrorotatory (optically active) catalyst

55  $L_a, D_a$  = d and L amino acid residue

In addition, as the absorption band at  $1270 \text{ cm}^{-1}$  in the IR spectra of polyalanine is attributed to its  $\alpha$ -helix structure, the characteristics of this method can be found in the variation of this band. That is to say, for poly-DL-alanine obtained using conventional tri-n-butylamine, an absorption band at  $1240 \text{ cm}^{-1}$  which is assigned to the random coil structure can be found, but the  $\alpha$ -helix absorption band resulting from stereoregularity cannot be found. On the other hand by the method according to this invention, an absorption at  $1270 \text{ cm}^{-1}$  can be recognized as in the case of poly-L-alanine.

70 Besides, the solubility of polyamino acid in some solvents is said to reflect the regularity in structure. For example, poly-DL-alanine obtained by the usual methods dissolves or swells in water, and dissolves in formic acid. On the other hand, poly-L-alanine or poly-D-alanine are insoluble in water and also in formic acid, and poly-alanine obtained from N - carboxy - DL - alanine anhydride by the method according to this invention is insoluble

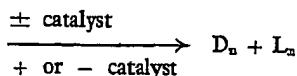
80 in formic acid.  
 These facts have been observed also in the cases of other amino acids such as poly-aspartate and polyglutamate, and verified in respect of many catalyst systems containing asymmetric carbon.

25 compound is also employed, there are no limitations to the amount of such organic compound, but it is preferably to use more than 0.3 mole % based on the amount of organometallic compound employed.

30 Generally speaking, the polymerization is carried out under reduced pressure or atmospheric pressure or an augmented pressure in an inert gas atmosphere. Though there are no special limitations as to the temperature of polymerization, it is usually carried out in a range between  $-20^\circ\text{C}$ . and  $150^\circ\text{C}$ , usually  $0^\circ$  to  $60^\circ\text{C}$ .

35 The properties of polyamino acids obtained by the method of this invention will now be described.

40 In carrying out this invention, N-carboxy-DL-amino acid anhydride undergoes asymmetric-selective polymerization, in an ideal case according to the following formula, and forms a mixture of d-d-sequence rich polyamino acid and L-L-sequence rich polyamino acid respectively:



45 The methods of obtaining optically active polyamino acid from racemic amino acid using optically active catalyst, and the results thereof, will be readily understood from the examples described later.

50 If the polymerization is not carried out completely but interrupted on the way, either one or the other enantiomeric isomer acquires priority and enters the polymer first on account of the stereo-selectivity (specificity) of the catalyst system, and therefore a polymer consisting of either one or the other enantiomeric isomer is obtained. But in fact a complete stereospecific polymerization can hardly be said to occur, and the obtained polymers, judging from their solubilities, can hardly be said to be exclusively poly-L-amino acid or poly-D-amino acid. Presumably in a chain there will be statistical contaminations by enantiomeric isomer of the other type, the net unbalance of asymmetric carbon atoms in the polymer and of polymer helices being observed as the optical rotatory power, and as the result optically active polyamino acid is obtained from racemic amino acid. But the difference between "D" and "L" in the total product decreases with the development of polymerization, and finally no optical activity is shown in a completely polymerized system. Nevertheless this polymer is essentially different from random polyamino acid.

55 90 95 100 105 110 115 120  
 In a case of optically inactive catalyst containing asymmetric carbon, simultaneous selective asymmetric polymerization occurs by means of both enantiomeric isomers of optically active catalyst. In this case rotatory power of the polymer cannot be detected, but

or interacts with organometallic compounds as possible.

The preferred organometallic compounds include methyl lithium, ethyllithium, n-propyl lithium, isopropyl lithium, n-butyl lithium, sec-butyl lithium, tert-butyl lithium, isobutyl lithium, isoamyl lithium, cyclohexyl lithium, cis-propenyl lithium, isobut enyl lithium, phenyl lithium, o-tolyl lithium, s-anisyl lithium, p-ethoxyphenyl lithium, p-dimethylaminophenyl lithium, 2-thienyl lithium, naphthyl lithium, pyridyl lithium, lithium methoxide, lithium ethoxide, lithium butoxide, n-butyl sodium, amylsodium, sodium methoxide, sodium sec-butoxide, potassium methoxide, potassium butoxide, potassium isopropoxide, potassium cyclohexylate, diethyl beryllium, diisopropyl beryllium, isopropyl beryllium hydride, di-n-butyl beryllium, dimethyl magnesium, diethyl magnesium, diphenyl magnesium, bis(triphenylmethyl)magnesium, magnesium methyl-ate, magnesium phenolate, diethyl calcium, diethyl strontium, dimethyl zinc, diethyl zinc, zinc ethoxide, di-n-propyl zinc, diphenyl zinc, diethyl cadmium, di-n-butyl cadmium, trimethyl aluminium, triethyl aluminium, tri-n-propyl aluminium, trisopropyl aluminium, triphenyl aluminium, dimethyl aluminium hydride, diethyl aluminium hydride, aluminium trimethoxide, aluminium triethoxide, aluminium triisopropoxide, dimethyl aluminium, dimethyl aluminium amide, dimethyl aluminium methyl mercaptide, lithium tetraphenyl aluminium, lithium aluminium tetra-methoxide, triethyl gallium, triphenyl gallium, dimethyl gallium amide and dimethyl gallium methoxide.

The preferred organic compounds having an asymmetric carbon atom which are used with the organometallic compounds include sec-butyl alcohol, active amyl alcohols, methyl vinyl carbinol, ethylethylene glycol, 1,2-pentanediol,  $\alpha$ -phenyl ethyl alcohol,  $\alpha$ -methyl- $\omega$ -phenylbutylalcohol, menthol, borneol, linalol, methylethylketone, phenyl benzyl alcohol,  $\alpha$ -methyl cyclohexanol, p-methyl benzyl ketone, sec-butylether,  $\alpha$ -methyl cyclohexanone, diisomylether, menthol methyl ether, borneol ethylether,  $\alpha$ -methyl propionaldehyde,  $\alpha$ -methyl-butyraldehyde,  $\alpha$ -hydroxy butyraldehyde, acetoacetic aldehyde, lactic acid, pantoic acid, oxy-glutaric acid, methyl succinic acid, tartaric acid, methyl ethyl acetic acid, methyl acetoacetate, ethyl lactate, methyl lactate, lactide, diethyl tartrate, pantolactone, methyl salicylate, mandelic acid, mandelic acid esters, bornyl acetoacetate, dimethyl malonate, menthyl cyanoacetate, cinchonine, cinchonidine, camphor, nicotine, alanine, phenyl alanine, aspartic acid phenyl alanine ether ester, N-acetylthreonine, menthyl cyancacetate, cyanhydrins, mandelonitrile, propyleneoxide, amylen oxide, glycidol, 2,3-epoxypentane, 2,3-epoxybutane, sec-butyl mercaptan, active

amyl mercaptan, sec-butylamine, 2-methyl-butylamine and di-sec-butylamine.

Organometallic compounds having an asymmetric carbon atom can be prepared by reacting the above-described organometallic compounds or metals of Groups I, II or III of the Periodic Table with the above-described organic compounds having an asymmetric carbon atom. Examples of organometallic compounds having asymmetric carbon atom are active amyl lithium, di-active amyl zinc, triactive amyl aluminium (i.e. compounds containing, respectively, one, two and three optically active amyl groups bonded to the metal atom), sec-butyl lithium, di-sec-butyl zinc, lithium - sec - butylate, aluminium - tri - sec - butylate, aluminium - tri - (2 - methylbutyl), aluminium monoethyl dimethylate, zinc monoethyl -  $\alpha$  - phenylethylate, lithium -  $\alpha$  - phenylethyl, zinc - di -  $\alpha$  - phenylethyl, dimethyl aluminium - sec - butylmercaptide, dimethyl aluminium active amyl mercaptide, dimethyl aluminium - (di - sec - butyl) - amide, aluminium tri-menthylate, lithium- $\alpha$ -phenylethylate, sec-butylborate and zinc-di-bornylate.

The method according to this invention is carried out by a technique nearly the same as the usual method of polymerization of N-carboxyaminoacid anhydrides. The polymerization is carried out in a solvent. There are no limitations on the solvents used, and any liquid that does not interfere with the polymerization by reacting with N-carboxy-amino-acid anhydrides or organometallic compounds can be used; therefore ethers, ketones, esters, nitriles, amides, sulphoxides, hydrocarbons and halogenated hydrocarbons can be utilized; for example, it is especially convenient to use one or a mixture of two or more of the following: dioxane, tetrahydrofuran, methylethylketone, ethyl acetate, acetonitrile, N,N-dimethyl formamide, dimethylsulphoxide, benzene, toluene, chloroform, dichloroethane and tetrachloroethane.

In addition, optically active or racemic compounds as mentioned above may be used as the solvent, separately or mixed with any of the solvents above mentioned, and this is advantageous in some cases.

As described above, when N-carboxy-DL-amino acid anhydride is polymerized by means of an optically active organometallic compound or a combination of an organometallic compound and an optically active organic compound, stereospecific polymerization is carried out and consequently optically active poly-amino acid can be obtained. Put in this case, for example, dextro-polyamino acid is not necessarily obtained from the dextra-compound because whether the polymer is dextrorotatory ( $[\alpha]_D > 0$ ) or levorotatory ( $[\alpha]_D < 0$ ) partly depends on the optical rotation of the optically active compound and the solvent used.

Besides, the total optical rotary power will

in the X-ray diffraction pattern and IR spectra of the polymer and in the properties of fibres obtained from this polymer a distinct difference can be recognized.

5 For example, poly-L-alanine shows a clear diffraction pattern at  $2\theta = 11.5^\circ$ , but poly-DL-alanine polymerized by tri-n-butyl amine scarcely shows a detectable pattern at  $2\theta = 11.5^\circ$ . In the case of poly-DL-alanine obtained by the method according to this invention (Examples 1—B and 1—C) a clear pattern can be observed at  $2\theta = 11.5^\circ$ .

The method according to this invention has been so far explained for the case of racemic, 15 that is to say, optically inactive, amino acids, but this method can also be applied in a similar manner to partly resolved amino acids which show optical activity, and satisfactory results can be obtained.

20 Polyamino acid polymerized from N-carboxy-DL-amino acid according to the

method described above also shows special characteristics in its physical properties on account of the difference in the content of stereosequence compared with polyamino acid obtained by the already known method. Fibres made from polyamino acid obtained by the present method exhibit superior tensile strength, and durability against chemicals and heat, compared with fibres made from random polyamino acid manufactured by the usual methods.

#### EXAMPLE 1

25 2.0 g samples of DL-alanine N-carboxy anhydride are dissolved in 50 cc of a mixture of anhydrous benzene and dioxane (4:1 in vol.), and are polymerized for 48 hours at 15°C. in a nitrogen-substituted glass ampoule, using various catalyst systems. The product obtained is treated with ether, extracted with hot methanol, and then dried under a reduced pressure. The results are shown in Table 1.

25

30

40

No.	Catalyst system	Conc. (Catalyst/monomer in moles)
1—A	tri-n-butyl amine	1/50
1—B	aluminium-ethyl di-1-methyleate (*)	1/50
1—C	[aluminium triethyl (+) menthol (-)]	1/50 2/50
1—D	aluminium triethyl	1/50

(\*) obtained by reacting aluminium triethyl and menthol

(-) in benzene

(+) both catalysts are dissolved in benzene and added to the N-carboxy anhydride solution simultaneously.

TABLE 1

No.	Polymer yield (%)	Reduced viscosity of polymer (*)	IR spectra	Solubility in formic acid	$[\alpha]_D^{25}$
1—A	80	0.52 (0.56)	1240 $\text{cm}^{-1}$	soluble	none
1—B	25	0.30 (0.58)	1270	insoluble	-2.0
1—C	28	0.42	1272	insoluble	-2.2
1—D	32	0.32	1240	swelling	none

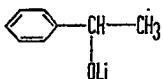
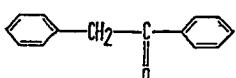
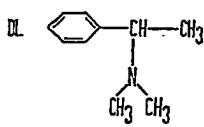
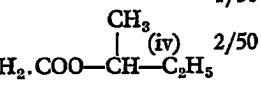
(\*) reduced viscosity measured at 25°C. in a concentration of 1.0 g/100 cc of dichloroacetic acid; the values in brackets are the results obtained in trifluoroacetic acid at the same concentration.

$[\alpha]_D^{25}$  is measured in dichloroacetic acid at 25°C.

EXAMPLE 2—5  
DL-alanine N-carboxy anhydride is polymerized in a similar manner as in Example 1.

The results are shown in the following Table II. 5

TABLE 2

No.	Solvent	Initiator	Initiator/ monomer in mole	Yield (%)	$\eta_{sp}/c$	IR spectra	$[\alpha]_D^{25}$
(i)							
2	benzene	(±) 	1/50	96	0.81	$1270 \text{ cm}^{-1}$ $1240$	—
(ii)							
3	benzene		1/50 2/50	72	0.53	$1270$ $1240$	—
(iii)							
4	dioxane		1/50 2/50	92	0.90	1270	—
5	dioxane		1/50 2/50	67	0.40	1268	—
(continued)							
2	insoluble			(i) lithium- $\alpha$ -phenylethylate			
3	insoluble			(ii) phenylbenzylketone			
4	insoluble			(iii) N-dimethyl- $\alpha$ -phenylethylamine			
5	insoluble			(iv) sec-butylacetooctate			

Polymerization temperature 30°C., Monomer concentration 5 wt. %,  
Polymerization period 24 hrs.

EXAMPLE 6-17  
2.0 g of  $\gamma$ -methyl-DL-glutamate N-carbonylhydride are polymerized under the following conditions, and the results can be seen in the following table. 5

No.	Initiator	Initiator concn.	Solvent	Yield %	Solubility in		I.R. spectra	$[\alpha]_{D}^{25}$
					Reduced viscosity	dichloroethane		
6	DL	1/70	chloroform	81	1.23	hardly soluble	620 cm <sup>-1</sup>	—
7	n-BuLi	1/50	„	95	0.67	soluble	650	—
8	n-BuLi	1/50	„	72	1.08	hardly soluble	620 650	—
		2/50						
9	Zn-di-D-bornylate	1/50	dioxane	91	0.92	swelling	620 650	+0.2
10	tri-n-butylamine	1/50	chloroform	92	1.31	soluble	650	—
11	Al(C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> H Menthol	1/50 2/50	chloroform	85	1.25	swelling	620	—
12	Al(C <sub>2</sub> H <sub>5</sub> )H $\alpha$ -phenylethylalcohol	1/50 2/50	„	82	1.31	swelling	620 650	—
13	Al(C <sub>2</sub> H <sub>5</sub> )(OCH <sub>3</sub> ) $\alpha$ -phenylethylalcohol	1/50 2/50	„	90	1.20	swelling	620 650	—
14	dimethylaluminium-methylmercapte $\alpha$ -phenylethylalcohol	1/50 2/50	„	85	1.09	swelling	620 650	—
15	dimethylaluminium-dimethylamide $\alpha$ -phenylethylalcohol	1/50 2/50	„	87	1.10	swelling	620 650	—
16	lithium aluminium hydride sec-butylalcohol	1/50 2/50	„	86	0.90	swelling	620 650	—
17	sec-butylborate	2/50	„	62	0.70	swelling	620	—

Polymerization temperature 35°C., Polymerization time 20 hrs.,

Monomer concentration 5 wt. %.

**EXAMPLE FOR COMPARISON**

5 Poly- $\gamma$ -methyl-L-glutamate obtained from  $\gamma$ -methyl-L-glutamate N-carboxy anhydride using tri-n-butylamine as initiator is insoluble in dichloroethane and shows a strong adsorption band at 620  $\text{cm}^{-1}$  (attributed to  $\alpha$ -helix structure).

**EXAMPLE 18**

10 20 g of  $\gamma$ -methyl-DL-glutamate N-carboxy anhydride are dissolved in a mixture of 150 of methylene chloride and 50 g of dioxane and the resultant solution is divided into two parts.

**EXPERIMENT (A)**

15 One of the two parts of the above solution is added with 0.2 g of tri-n-butyl amine and is polymerized at 25°C. for 24 hours, and the transparent solution is spun into a mixture of acetone and methanol (1:1 vol.) through a

20 nozzle; there is obtained a white and fragile

fibrous substance. This material cannot be stretched and it is impossible to obtain a strong fibre. The viscosity of the solution of this polymer is 1.01.

**EXPERIMENT (B)**

25 The other part of the said solution is added with 0.1 g of aluminium triethyl and 10 g of D-camphor, and polymerized at 25°C. for 24 hours. The product is spun through a nozzle into a mixture of acetone and methanol (1:1 vol.). This fibre can be stretched in a water bath and is stretched 150%, and there is obtained a fibre which is insoluble in carbon tetrachloride and O-dichloro benzene. This filament exhibits a tenacity of 1.2 g/denir and an elongation of 22% and shows orientation.

**EXAMPLES 19—23**

30 Similar experiments are carried out using  $\beta$ -methyl-DL-aspartate N-carboxy anhydride and the following results are obtained.

40

No.	Initiator	Initiator/ monomer in mole	Solvent	Yield %	$[\alpha]_D$	m.p.	Solubility
13	n-Bu <sub>3</sub> N	1/80	{ dioxane 1 chloroform 6	72	—	181—182	Soluble in chloroform
14	{ AlEt <sub>3</sub> 1-Nicotine	1/50 2/50	„	42	-10.5	279	Slightly soluble in chloroform
15	{ ZnEt <sub>2</sub> DL-methyl aspartate	1/50 2/50	„	62	—	260	„
16	Aluminium-tri- active-amylate	1/50	„	50	—	200	„

Polymerization temperature 50°C., Polymerization time 48 hrs.,

Monomer concentration 5 wt. %.

**EXAMPLE 24**

5.0 g of DL- $\beta$ -phenylalanine N-carboxy anhydride dissolved in 20 ml of dioxane are added with 0.05 g of aluminium triethyl and DL - N,N - dimethyl  $\beta$  - phenylalanyl - N,N - dimethylamide, mixed, and then polymerized at 30°C. for 24 hours, and subsequently treated with diethylether, acidic methanol 50 hydrochloric acid, and then methanol. There is obtained poly-DL-phenylalanine which is insoluble in dioxane. Poly-DL- $\beta$ -phenylalanine similarly produced using n-butyl amine as initiator is soluble in dioxane, but on the

other hand poly-L-phenylalanine produced from L-phenylalanine N-carboxy anhydride is insoluble.

**EXAMPLES 25—28**

55 5 g of DL-methionine N-carboxy anhydride are dissolved in 20 ml of dioxane and polymerized using the following initiator at 35°C. for 40 hours. Polymethionine thus obtained is dissolved in m-cresol and cast to a film by evaporation. The film exhibits a higher tensile strength than the film obtained by using as initiator tri-n-butyl amine. The results are shown in the following table.

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No.	Initiator		Yield %	$\eta_{sp}/C$	Tensile strength	Elongation
25	$\left\{ \begin{array}{l} Al(C_2H_5)_3 \\ Camphor \end{array} \right.$	0.1 g 2.1	64	0.60	22 kg/mm <sup>2</sup>	30%
26	$\left\{ \begin{array}{l} Al(C_2H_5)_3 \\ Menthol (+) \end{array} \right.$	0.1 2.0	62	0.52	20	32
27	$\left\{ \begin{array}{l} Al(C_2H_5)_3 \\ sec-butanol \end{array} \right.$	0.1 2.0	42	0.45	17	35
28	tri-n-butyl-amine	0.1	90	0.62	12	10

## WHAT WE CLAIM IS:—

1. A method of producing polyamino acids which comprises polymerizing N-carboxy-DL- $\alpha$ -amino acid anhydrides containing at least one asymmetric carbon atom using as the catalyst an organometallic compound which contains an asymmetric carbon atom, of a metal of Groups I, II or III of the Periodic Table.

2. A method of producing polyamino acids which comprises polymerizing N-carboxy-DL- $\alpha$ -amino acid anhydrides containing at least one asymmetric carbon atom using as the catalyst an organometallic compound of a metals of Groups I, II or III of the Periodic Table, in the presence of an organic compound containing both an asymmetric carbon atom and an active hydrogen atom (which includes enolizable hydrogen).

3. A method of producing polyamino acids according to Claim 2 in which the organic compound having both an asymmetric carbon

atom and an active hydrogen is optically active. 25

4. A method of producing polyamino acids according to Claim 1 or Claim 2 or Claim 3 in which the organometallic compound is optically active.

5. A method according to Claim 3 or Claim 4 for obtaining optically active polyamino acids from N-carboxy-DL- $\alpha$ -amino acid anhydrides. 30

6. A method of producing polyamino acids as claimed in Claim 1 or Claim 2 and substantially as described in any of the Examples.

7. Optically active and optically inactive polyamino acids produced according to any of the preceding claims. 35

8. Moulded products made from polyamino acids as claimed in Claim 7. 40

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